PROCEEDINGS OF SCIENCE

A New ^{82}Se detector for Neutrinoless Double Beta Decay Searches

Emilio Ciuffoli[a,*] **on behalf of the NνDEx Collaboration**

[a] *Institute of Modern Physics, Chinese Academy of Sciences, Nanchanglu 509, Lanzhou, China*

E-mail: emilio@impcas.ac.cn

NνDEx (No neutrino Double-beta-decay Experiment) is a new Se-based TPC detector that will be placed in China Jinping Underground Laboratory (CJPL) looking for neutrinoless double beta decay. NνDEx-100, the experiment phase with 100 kg of SeF_6 gas, is currently being built and planned to be completed with installation at CJPL around the year 2025. I will present the current status of the experiments and the perspectives for future developments. SeF_6 has very high electronegativity; for this reason, the electrons will recombine very quickly and the particles traveling toward the readout plane will be negative ions. A new kind of sensor, Topmetal-S, has been developed: it will allow us to read out the drifted charge and reconstruct the energy of the event with great precision even without physical amplification like electron avalanche. The main advantages offered by NνDEx are two: firstly, the large rock overburden would decrease significantly the cosmogenic muon background. Second, the high Q-value of ^{82}Se ($\sim$3 MeV) will place the Region Of Interest above the energy range of the large majority of the environmental gamma's, allowing us to achieve an incredibly low-background environment, which ensures excellent perspectives for scalability.

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1. Introduction

Among the problems still open in particle physics, one of the most important is the origin and nature of the neutrino mass. In the Standard Model (SM), neutrinos are supposed to be massless; the observation of neutrino oscillations, however, proved definitively that this cannot be the case. Moreover, neutrinos are the only particles in the SM that could have a Majorana mass term: if such a term is present, neutrinos would be their own antiparticles and lepton-violating processes would be allowed at tree level, with significant consequences in many different fields. For this reason, many experiments are looking for neutrinoless double beta ($0\nu\beta\beta$) decays, the "smoking gun" that would prove the Majorana nature of neutrinos. The main challenge these experiments must overcome is that the cross-section for $0\nu\beta\beta$ decay is proportional to $m_{\beta\beta}^2$, where $m_{\beta\beta}$ is the effective Majorana mass of the electron neutrino, which is very small. As a consequence, such a process is strongly suppressed, and both an incredibly low-background environment and very good energy resolutions are key requirements for any $0\nu\beta\beta$ experiment.

2. NνDEx

NνDEx (No Neutrino Double beta decay Experiment) [1] will look for $0\nu\beta\beta$ decays using a High-Pressure (HP) SeF_6 Time Projection Chamber (TPC), a design that was first suggested in 2018 [2]. The source of $\beta\beta$ decay will be ^{82}Se, which is present in natural Se with an abundance of 8.7%; the main advantage of this set-up is the high Q-value of the decay, 2.996 MeV, which places the Region of Interest (ROI) well above most of the natural background. ^{82}Se is or will be used by other experiments as well, some already operational, others under development: CUPID-0 [6] (bolometer, operational), Super-NEMO [7] (tracker-calorimeter; demostrator operational, 100-kg experiment proposed) , Selena [8] (CMOS pixel detector, under development) and IFC [9] (TPC, under development).

The detector will be placed at China Jinping Underground Laboratory (CJPL): with 2400 m rock overburden (6700 m water equivalent) CJPL has the thickest natural rock shield in the world, which will considerably reduce the background due to cosmic muons. The first phase of NνDEx will be NνDEx-100, using 100 kg of SeF_6 at 10 atmospheres. In the first run, scheduled to start in 2025, natural Se will be used. A schematic design of the detector station for NνDEx-100 is shown in Fig. 1 [3]: starting from the most external layer, we have the Lead Shielding (LS, indicated in gray), the HDPE Shielding (yellow), the Stainless Steel Vessel (SSV), as well as the pipes and the holder that will keep the SSV in place, all indicated in dark gray, the Inner Copper Shielding (ICS, orange), the Field Cage (FC, green) and the gas (blue).

Working with SeF_6, however, presents also some challenges that must be overcome: first of all, the gas itself is toxic, which means that security measures must be implemented to avoid dispersion of SeF_6 in the environment [1]. The detector will be placed in an airtight clean room and the experiment will be controlled remotely. The clean room will also contain a sufficient amount of a reagent (potassium iodide, KI); which will constitute the second line of defense. A pressure relief tank will be set up to contain the gas in case of emergency. When the gas needs to be removed from the room, it will be stored in a cold trap and, after every modification, the whole system will be checked with SF_6, a gas with similar chemical properties.

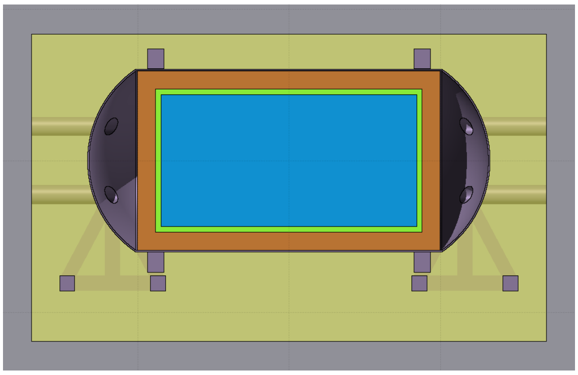

Figure 1: Schematic design of the detector station for NνDEx-100 [3]

Moreover, SeF_6 is strongly electronegative, which means that the electrons will recombine almost immediately and the particles drifting through the high-voltage plate will be negative ions. A new kind of sensor, Topmetal-S [4, 5], is being developed to detect the negative ions and achieve a good energy resolution despite the lack of electron avalanche multiplication. For NνDEx-100, we expect to achieve 1% FWHM energy resolution at $Q_{\beta\beta}$, which means that our ROI will be 2.98-3.01 MeV. Two tape-outs of the sensor were already conducted, with a third one under production; some issues identified in the first tape-out, which led to a lower signal collected, were corrected in the second tap-out, which is currently being tested.

3. Background And Sensitivity

Several sources of environmental background should be taken into account.

γ rays will be produced from the decays of radioactive isotopes, which will be present in traces in the rocks surrounding the experimental hall and in the material of the detector itself (α and β particles can be emitted as well, but they are much easier to stop, and will not be an issue unless produced directly in the fiducial volume), The LS, which will be 20 cm thick, will stop the vast majority of the environmental γ's, significantly reducing the background, the γ's coming from radioactive contamination in the detector cannot be stopped in this way, however: in Tab. 1 it is reported the contribution to the γ-induced background from different parts of the detector station. We can note that the main contributions come from the FC: indeed, the ICS will stop most of the γ's coming from inside the LS, but γ's from FC cannot be shielded. In total, the background due to γ from natural radioactivity is estimated to be 0.42 events/year [1]. Please note that topological cuts have not been taken into account so far: using neural networks to study the topological information associated with $0\nu\beta\beta$ events, it should be possible to reduce even further the background by 1 order of magnitude [1].

While cosmic rays do not represent a concern at CJPL, they can still activate nuclei when the detector is assembled on the surface. If these isotopes have long enough half-lives, part of them can survive long enough to provide a source of background for our experiment. The main concern is ^{56}Co, which can be created by the interactions of cosmogenic neutrons with the ICS. Without any kind of cool-down period, the background due to ^{56}Co would be estimated at around 3400 events in ROI/year, vastly dominant. Its lifetime, however, is 77 days, which means that, if it is stored

Table 1: γ background from different parts of the detector station [1]

Source	Evts/yr	10^5Evts/(keV kg yr)	Source	Evts/yr	10^5Evts/(keV kg yr)
Walls	0.004	0.12	LS	0.003	0.09
HDPE	0.005	0.16	SSV	0.026	0.86
ICS	0.050	1.67	FC	0.330	10.99

underground, after 3 years the ^{56}Co background would be reduced down to 0.002 events/year and be safely neglected.

Fast neutrons can generate background events as well. If they arrive in the fiducial volume, they can be absorbed and create unstable isotopes there, whose decays can be mistaken for a $0\nu\beta\beta$ events; this kind of background, however, is subdominant in all the configurations we have studied [3]. When neutrons are absorbed, moreover, γ rays are usually emitted, whether or not the resulting isotope is unstable; if their energy is larger than 3 MeV, they can be a source of background. HDPE is needed in order to stop the fast neutrons. We found that the most efficient way to place the HDPE shielding is to fill the space between the LS and the SSV. This is not enough to reduce sufficiently the neutron-induced background, however: an additional external HDPE shielding (30 cm thick) must be placed outside the LS to bring the fast neutron background down to 0.03 events in ROI per year [3].

Considering a 90% reduction thanks to topological cuts, the total estimated background rate would be 0.05 events/year, which would lead to an expected sensitivity of 3×10^{25} years for a 5-year run, assuming the ROI would include 75% of the $0\nu\beta\beta$ events. However, since the background is very low, the ROI could be expanded in order to increase the coverage: in this case, the sensitivity would increase up to 4×10^{25}. If enriched Se ($\geq$90% ^{82}Se) is used, the sensitivity would be increased up to 4×10^{26} years.

The high Q-value of ^{82}Se and high overburden of CJPL will allow NνDEx to have a very low background index, giving excellent prospects for scalability in the future.

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